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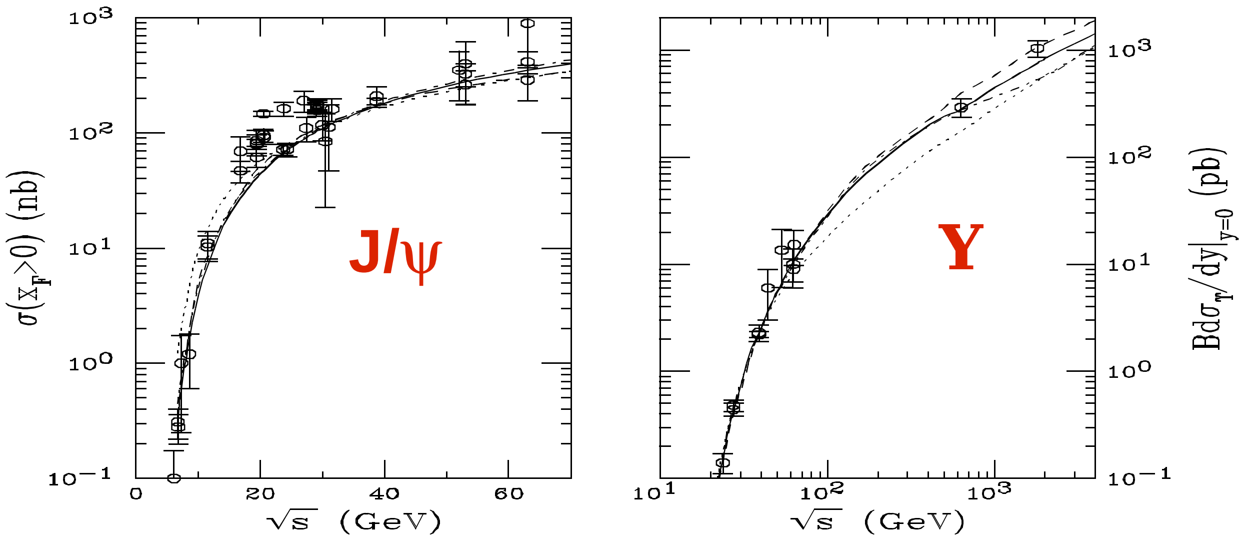
Heavy Flavours in Heavy-ion Collisions in CMS Experiment at LHC

for CMS collaboration

From SPS and RHIC to LHC

Increase energy $\sqrt{s_{NN}}$ = 17-200 GeV → 5500 GeV

- **Plasma hotter and longer lived than at RHIC**
- **Unprecedented gluon densities**
- **Access to lower x, higher Q^2**
- **Availability of new probes**



Quarkonia

(J/ψ, ψ'; Υ,Υ',Υ")

large cross section

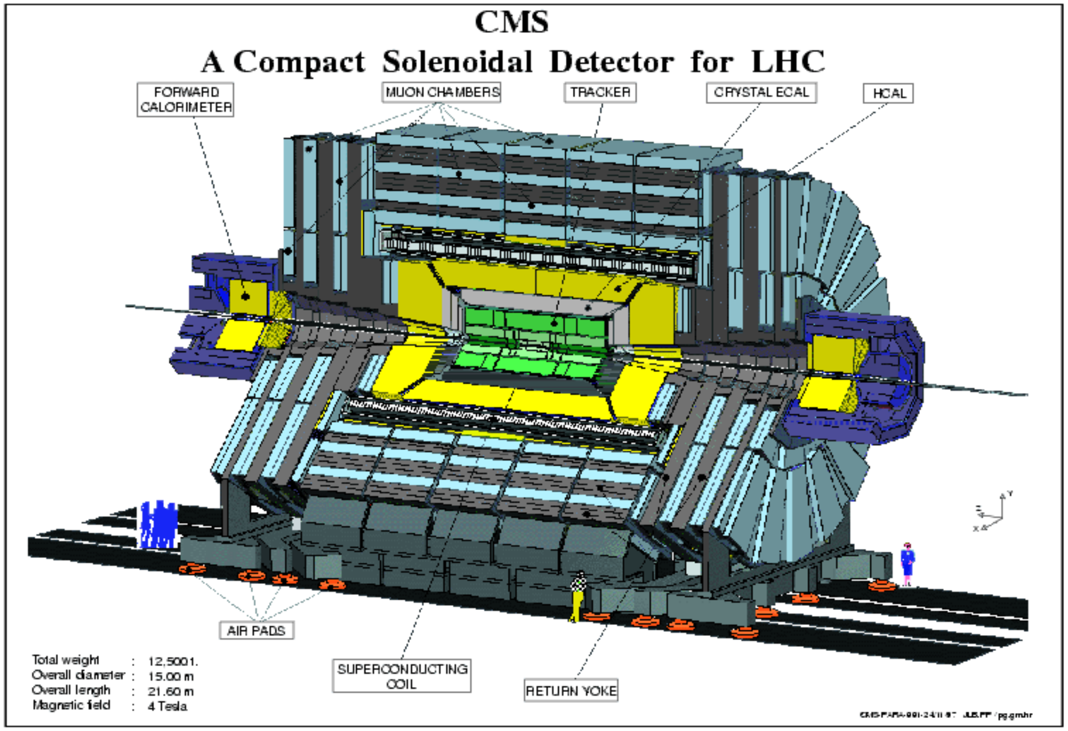
↓

high statistics

Different melting for Υ,Υ',Υ"

Large cross section for heavy quarks (b,c). Observation of medium induced energy loss in high mass dimuon spectrum and secondary J/ψ.

CMS detector



- **Silicon Tracker**

  $|\eta| < 2.4$

- **Electromagnetic Calorimeter**

  $|\eta| < 3.0$

- **Hadron Calorimeter**

  barrel and endcap

  $|\eta| < 3.0$

  with HF-calorimeter up to

  $|\eta| < 5.2$

- **Muon Chambers**

  $|\eta| < 2.4$

Magnetic field: 4 Tesla

+ CASTOR detector

$5.3 < |\eta| < 6.4$

+ Zero-degree calorimeter

+ TOTEM

CMS as a detector for Heavy Ion Physics

Tracker
- wide rapidity range $|\eta| < 2.4$
- excellent momentum resolution:

$\Delta p/p < 1\text{-}2\%$ for p_T less than 100 GeV

Calorimeters
- fine grained

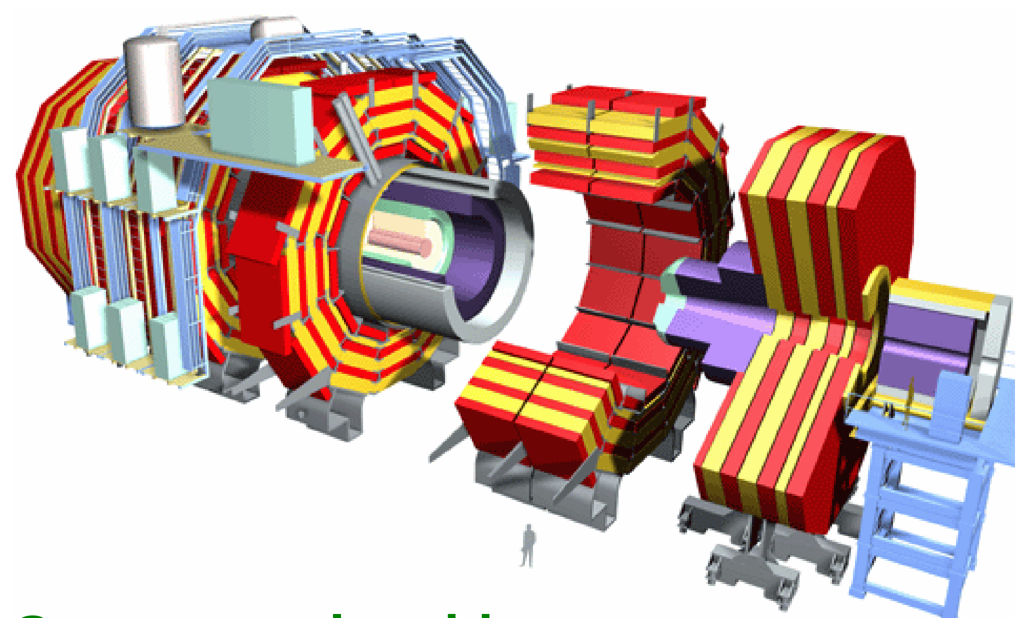
(up to $\Delta\eta \times \Delta\varphi = 0.087 \times 0.087$)
- high energy resolution
- hermetic coverage

  up to $|\eta| < 5.2$,

  up to $|\eta| < 6.4$ (using CASTOR)

Muon stations
- wide rapidity range $|\eta| < 2.4$

DAQ and Trigger
- high rate capability for AA, pA, pp
- inspection of fully built events at high level trigger of the most of HI events.



Compact solenoid
- strong magnetic field (4 Tesla)

Signal and background simulation

Signal events:

- **Y, Y', Y'', J/ψ, $\psi' \rightarrow \mu^+\mu^-$ are generated according to calculation by R. Vogt**
- **$Z^0 \rightarrow \mu^+\mu^-$ is generated with PYTHIA**
- **B $\rightarrow \mu$+X, B $\rightarrow$ J/ψ+X are generated with PYTHIA**

$$\sigma_{AA} = A^{2\alpha}\sigma_{pp} \quad \text{with} \quad \alpha = 1 \quad \text{for } Z^0$$
$$\alpha = 0.95 \quad \text{for Y,Y',Y''}$$
$$\alpha = 0.9 \quad \text{for J/}\psi$$

Background events are generated with HIJING with high and low multiplicity assumptions.

High multiplicity assumption: $dN_{ch}/d\eta$ = 5000 for central PbPb event

Low multiplicity assumption: $dN_{ch}/d\eta$ = 2500 for central PbPb event

Signal events are combined with background AA events.

$\mu^+\mu^-$ reconstruction algorithm

Primary vertex determination

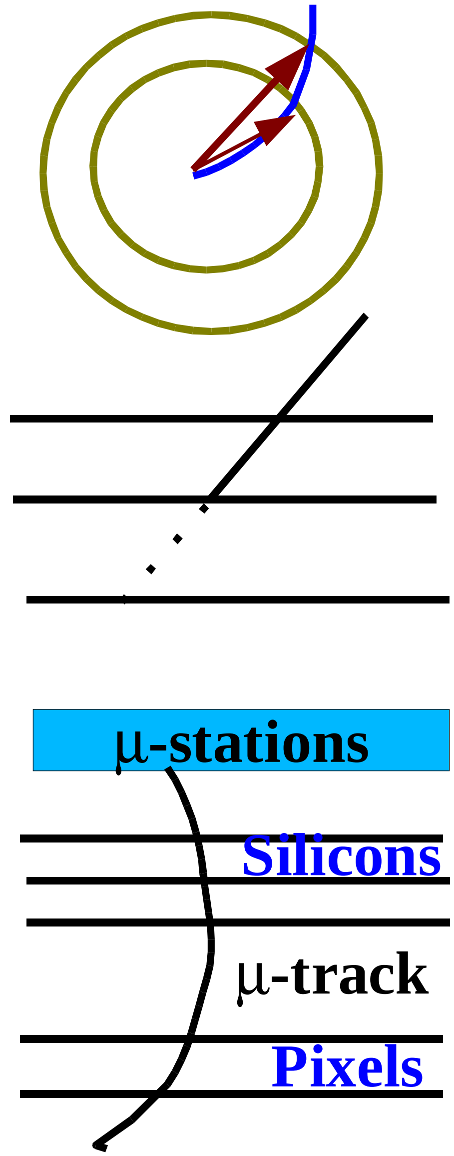
- select pairs of pixel hits with $\Delta\varphi$ giving $0.5 < p_T < 5$ GeV
- extrapolate each pair in RZ to the beam line

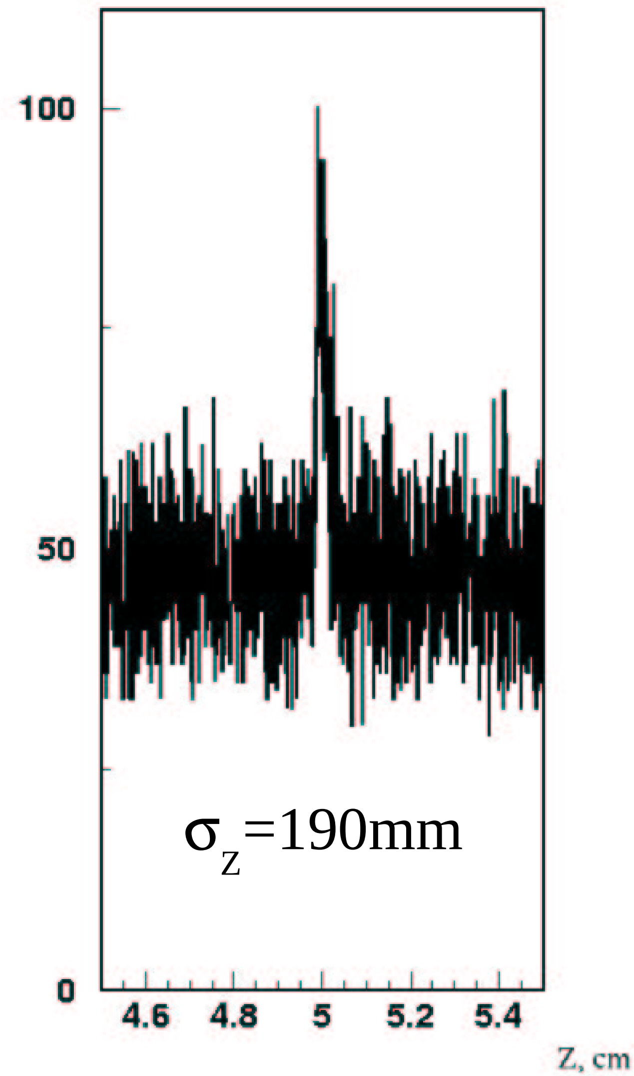
Track finding

- start from track candidate in muon stations
- extrapolate inwards from plane to plane using vertex constraints

Track selection by cuts

- fit quality (χ^2)
- vertex constraint





J/ψ spectra for different nuclei, high multiplicity assumption

For Pb+Pb at integrated luminosity 0.5 nb^{-1}

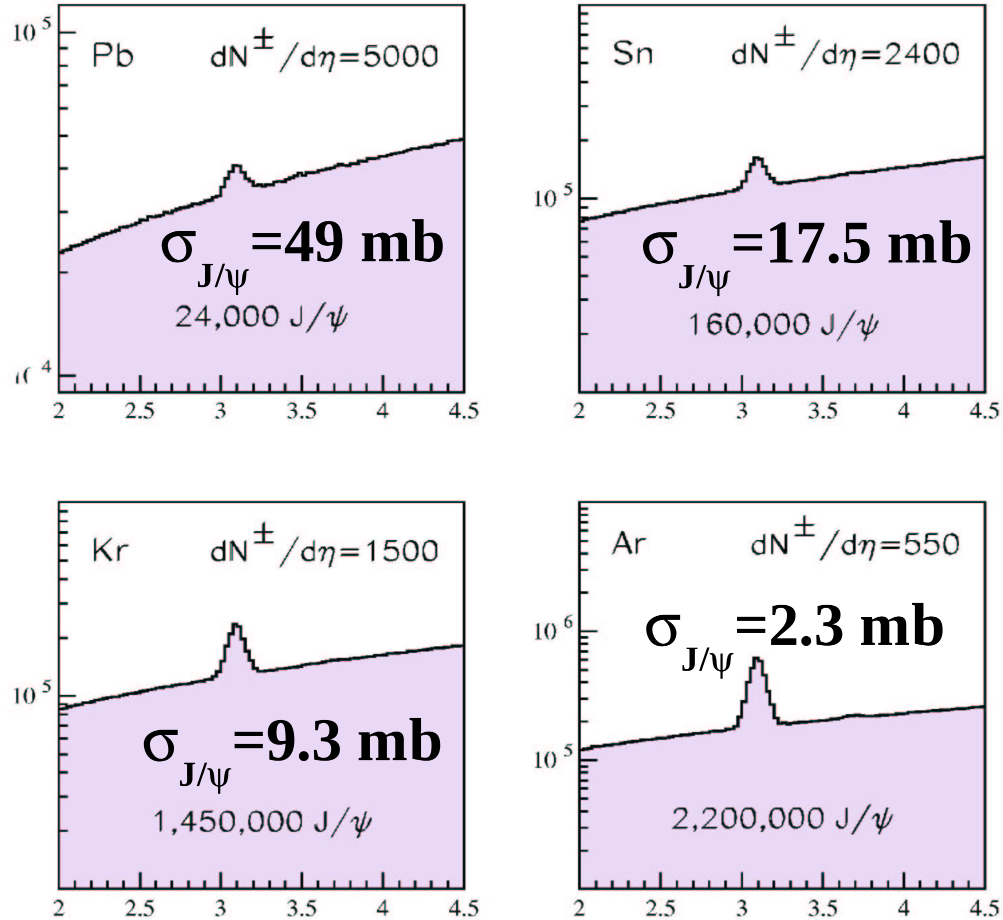
Combinatorial background:

- **π/K decays into μ**
- $c\bar{c}$ and $b\bar{b}$ production pp cross-section $\sigma_{cc} = 6.3\text{mb}$, $\sigma_{bb} = 0.19\text{mb}$

Mixed sources, i.e.

- **1 μ from π/K + 1 μ from J/ψ**
- **1 μ from b/c + 1 μ from π/K**

No trigger efficiency but $p_T^{\mu} > 3.5$ GeV/c



Opposite sign dimuon invariant mass, GeV/c^2

Full GEANT simulation for reconstruction efficiency in tracker and dimuon mass resolution. Mass resolution ~50 MeV/c^2.

J/ψ spectra for different nuclei, low multiplicity assumption

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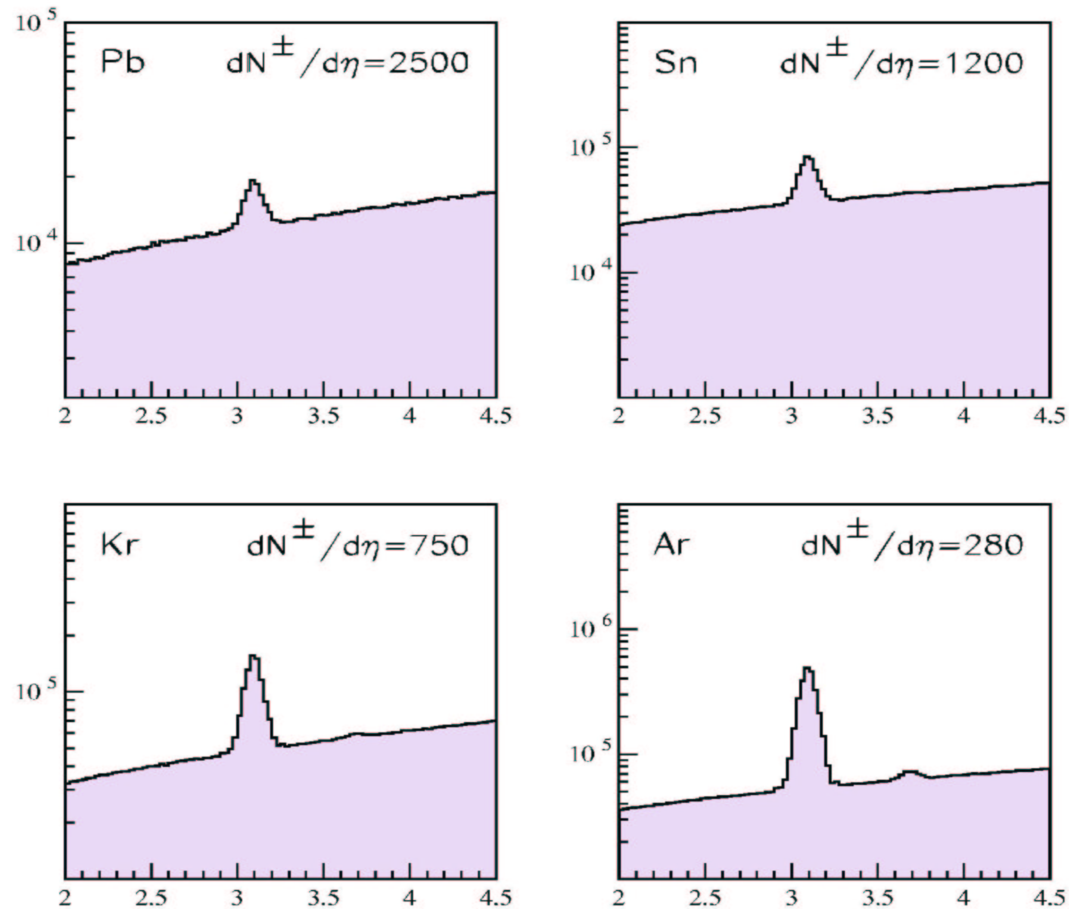

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Υ spectra for different nuclei, high multiplicity assumption

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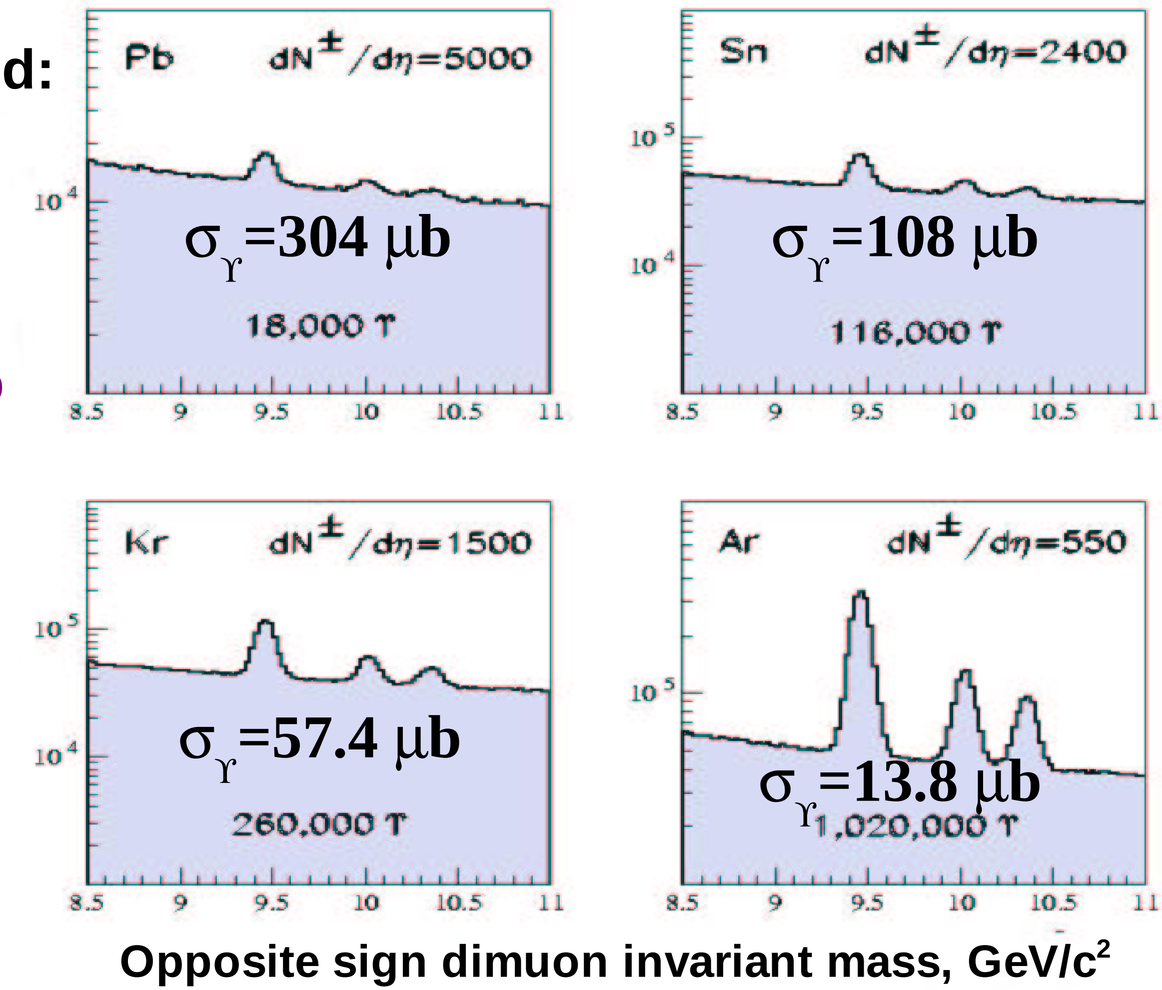

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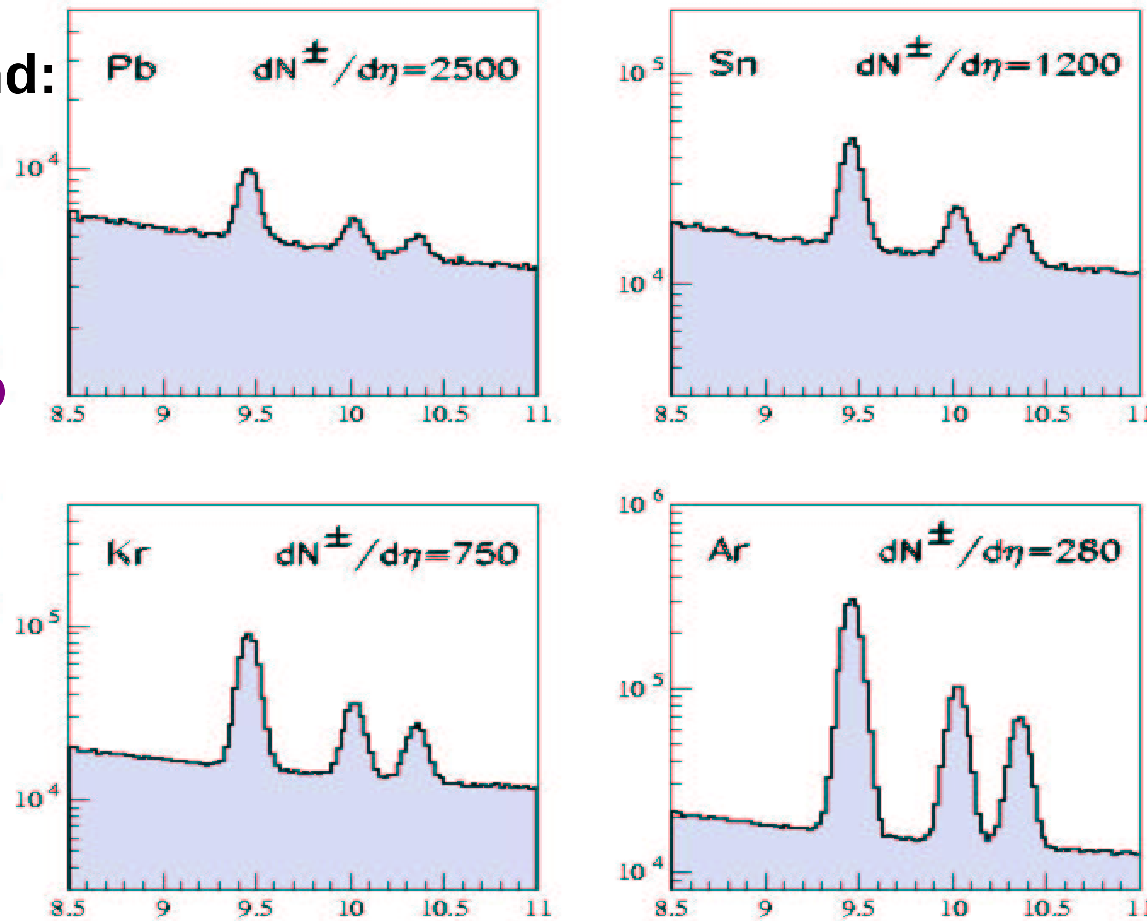


Opposite sign dimuon invariant mass, GeV/c^2

Full GEANT simulation for reconstruction efficiency in tracker and dimuon mass resolution. Mass resolution ~50 MeV/c^2.

Background composition in Y mass range

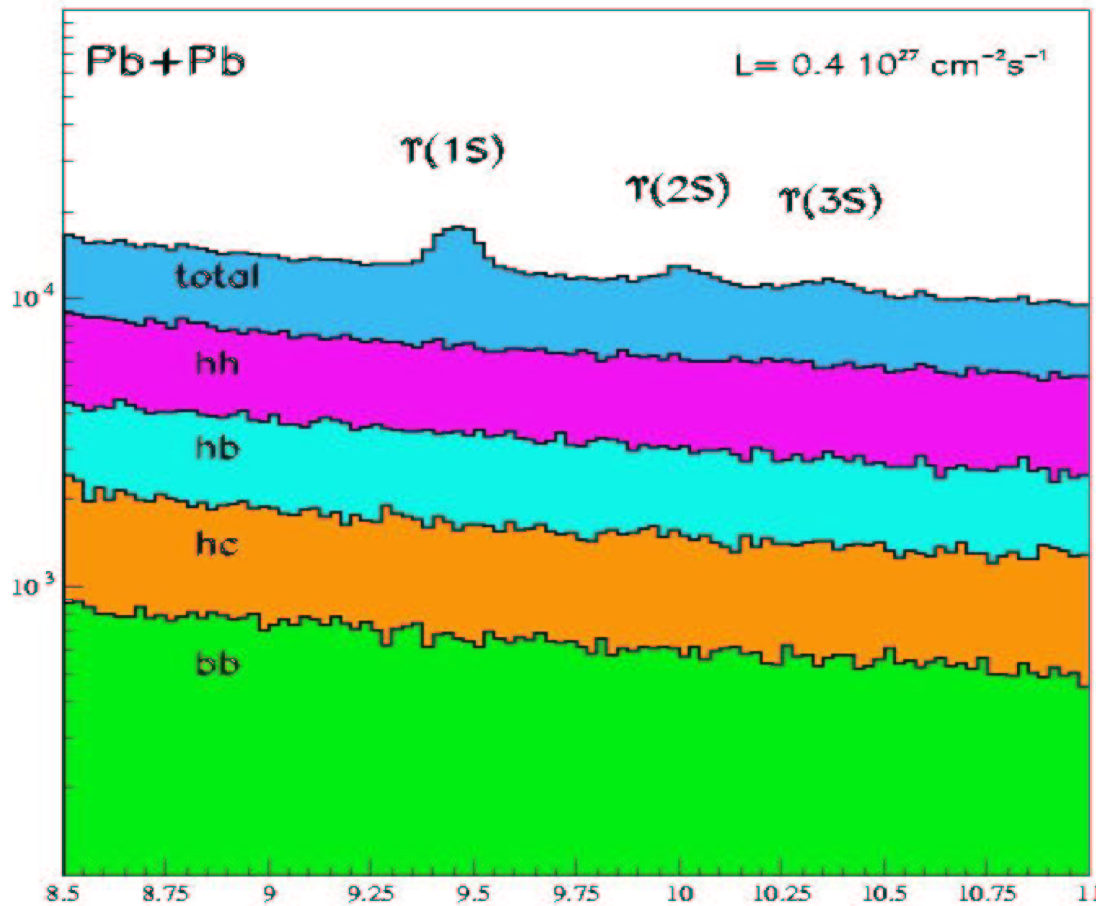
For Pb+Pb at integrated luminosity 0.5 nb^{-1}
high multiplicity assumption

hh **π/K decays into μ**

$c\bar{c}$ c decays into μ

$b\bar{b}$ b decays into μ

hb,hc **1 μ from b/c**
1 μ from π/K

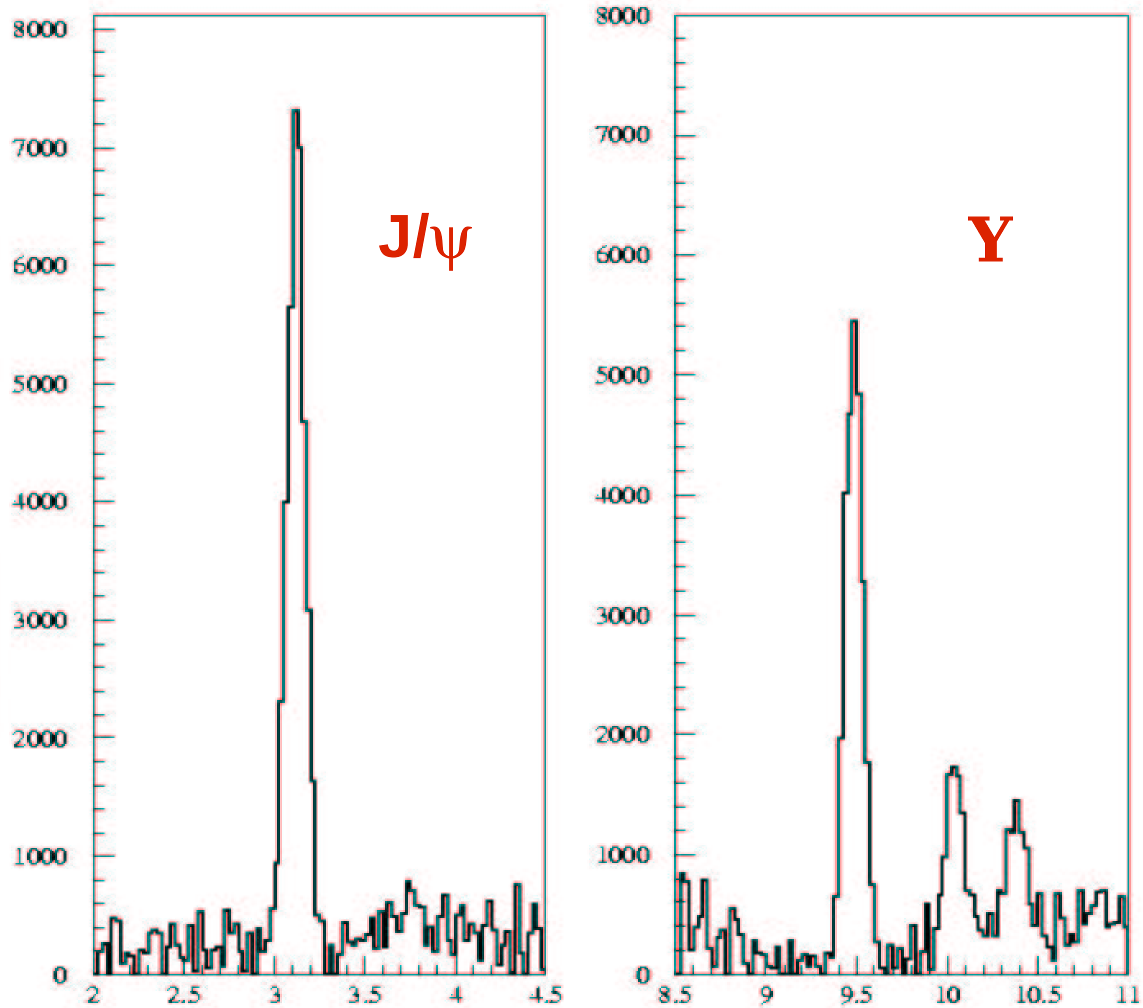


Opposite sign dimuon invariant mass, GeV/c^2

J/ψ, Υ spectra for PbPb after background subtraction

After subtraction of uncorrelated background using like-sign dimuons

$$S = OS - 2\sqrt{(N^{++}N^{--})}$$



Opposite sign dimuon invariant mass, GeV/c²

Signal/Background ratios (high multiplicity - low multiplicity)

		PbPb	SnSn	KrKr	ArAr
S / B	J/ψ	0.2 - 0.5	0.4 - 1.1	0.7 - 1.8	2.0 - 6.8
	ϒ	0.4 - 0.9	0.7 - 1.9	1.5 - 4.3	5.3 - 15.6
S / sqrt(S+B)	ϒ	69 - 93	220 - 276	396 - 460	925 - 978
	ϒ'	24 - 38	84 - 123	165 - 218	447 - 512
	ϒ''	16 - 26	55 - 86	113 - 157	325 - 391

Mass window: $M_{res} \pm 50$ MeV / c^2

CMS muon trigger for heavy ions

The heavy ion Level 1 (L1) muon trigger is a single muon with the lowest p_T cut in full region $|\eta|<2.4$.

in barrel $0.<|\eta|<1.5$: $p_T$min = 4 GeV/c (trigger efficiency=90%)

$p_T$min = 3.5 GeV/c (trigger efficiency=80%)

in endcap $1.5<|\eta|<2.4$: $p_T$min from 3.5 GeV/c to 1.5 GeV/c

The second muon is added at Level 2 (L2).

This L1 baseline allows use different combination of patterns from different CMS muon chambers detectors: Drift Tube, Cathode Strip Chambers, Resistive Plate Chambers (schema OR).

L2 is done on the on-line farm.

The relatively low luminosity of heavy ion beams allows this less restrictive L1 trigger.

J/ψ and Y are generated according inclusive (η,p_T) distributions for central Pb+Pb and are forced to decay into $\mu^+\mu^-$ within GEANT simulation.

J/ψ triggering (p_T and η dependence)

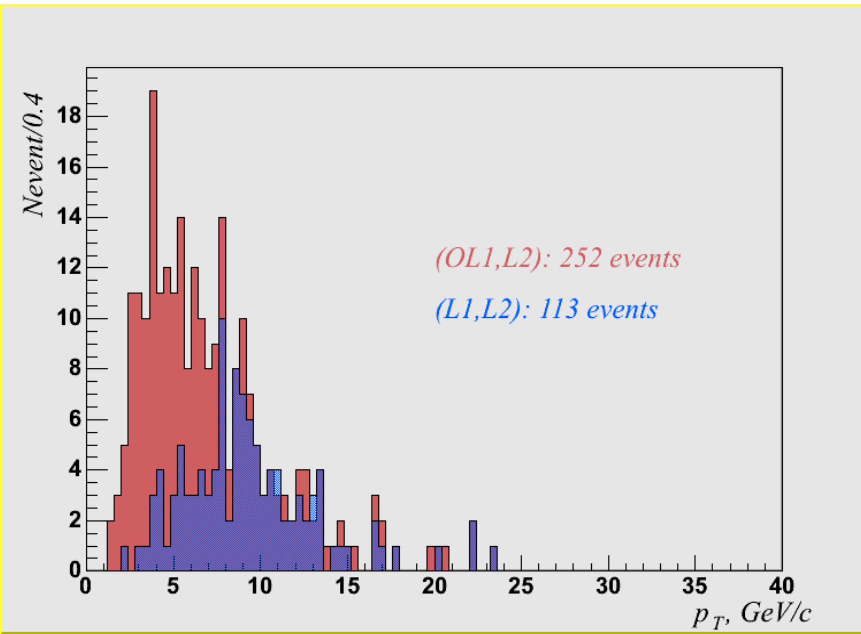
Two different optimization at Level 1:

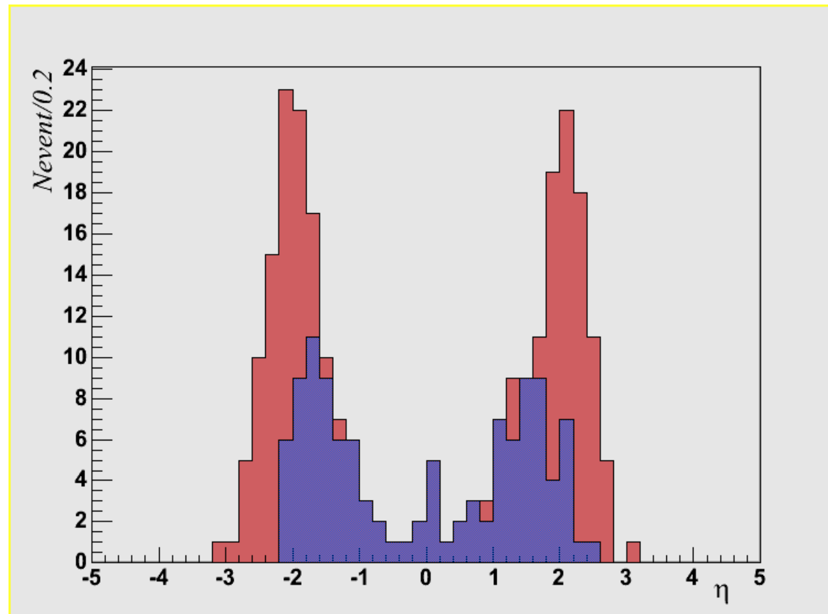
L1 optimized for high luminosity pp

OL1 (low quality muon candidate) proposed for HI

Trigger condition: two opposite sign candidates at Level 1 or two opposite sign candidates at Level 2

(OL1,L2) 252 events, (L1,L2) 113 events.





Trigger efficiency: 0.97% (OL1-L2 chain)
0.44% (L1-L2 chain)

26000 J/ψ were generated

Υ triggering (p_T and η dependence)

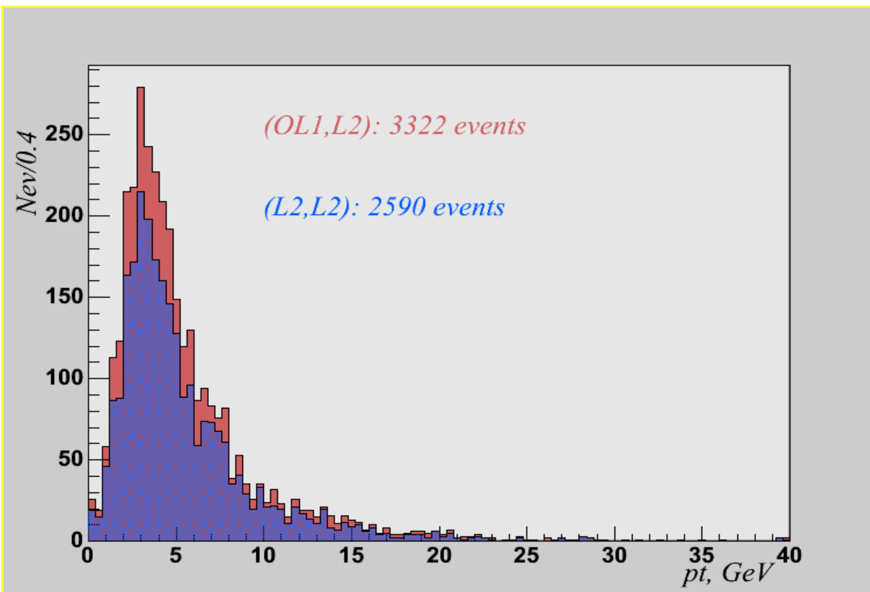
Two different optimization at Level 1:

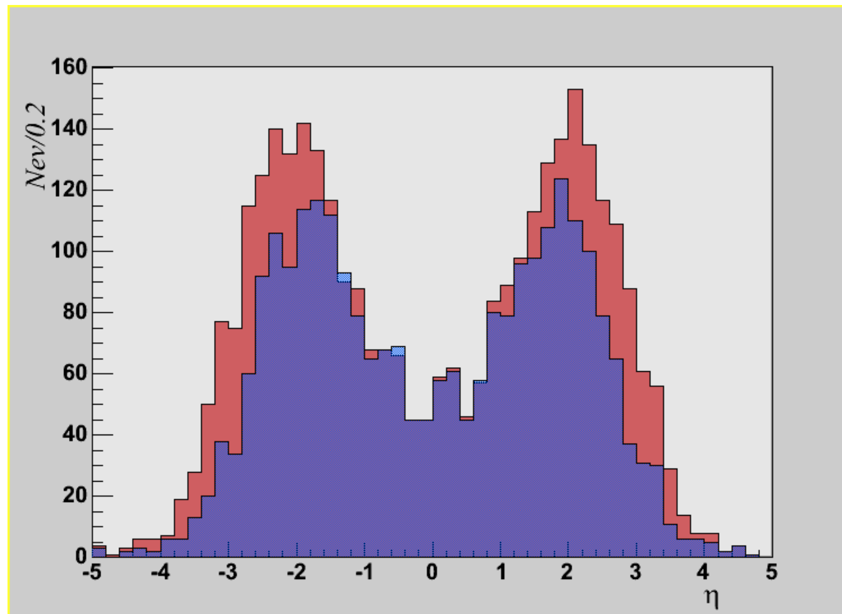
L1 optimized for high luminosity pp

OL1 (low quality muon candidate) proposed for HI

Trigger condition: two opposite sign candidates at Level 1 or two opposite sign candidates at Level 2

(OL1,L2) 3322 events, (L1,L2) 2590 events.





Trigger efficiency: 21% (OL1-L2 chain)

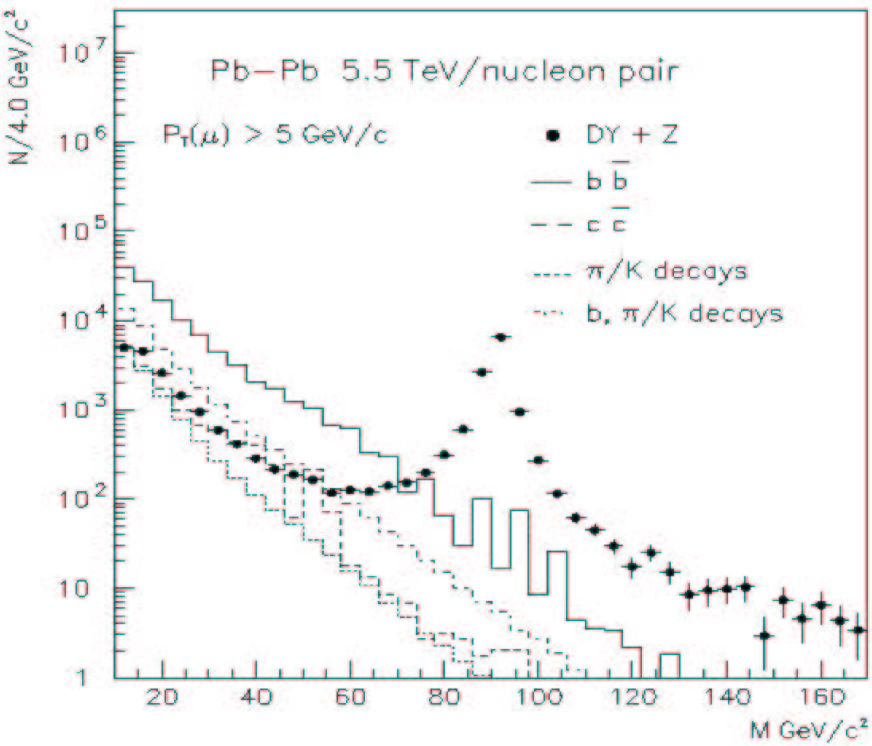
16.5% (L1-L2 chain)

15700 Υ were generated

$Z^0 \rightarrow \mu^+\mu^-$ detection at CMS

$$\sigma_{AA} = A^{2\alpha}\sigma_{pp} \quad \text{with } \alpha = 1$$

σ_{pp} was taken from PYTHIA,
correction k=2 for $c\bar{c}$ and $b\bar{b}$ and k=1.3-1.5 for Z^0, W, tt



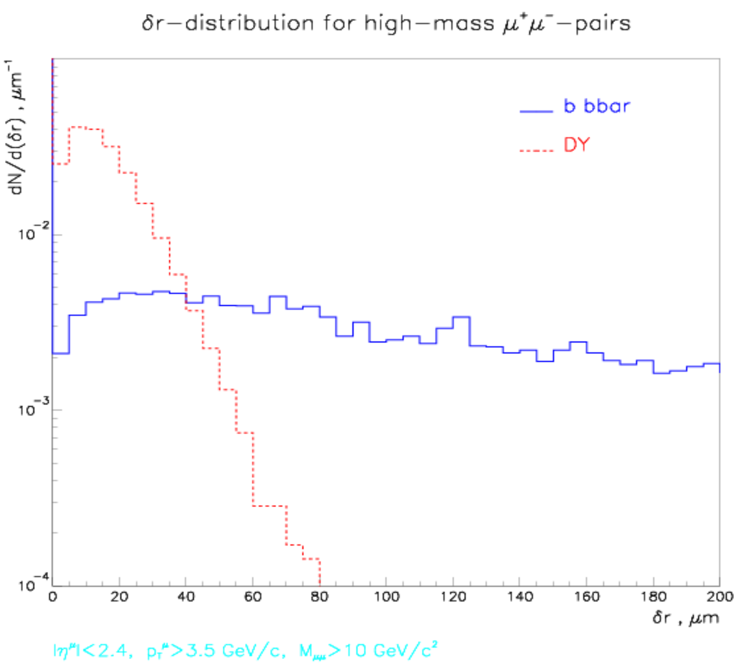
HIJING was used for AA event

The expected number of $Z^0 \rightarrow \mu^+\mu^-$: ~$10^4/1.3\times10^6$ s of Pb-Pb running at $L=10^{27}cm^{-2}s^{-1}$.

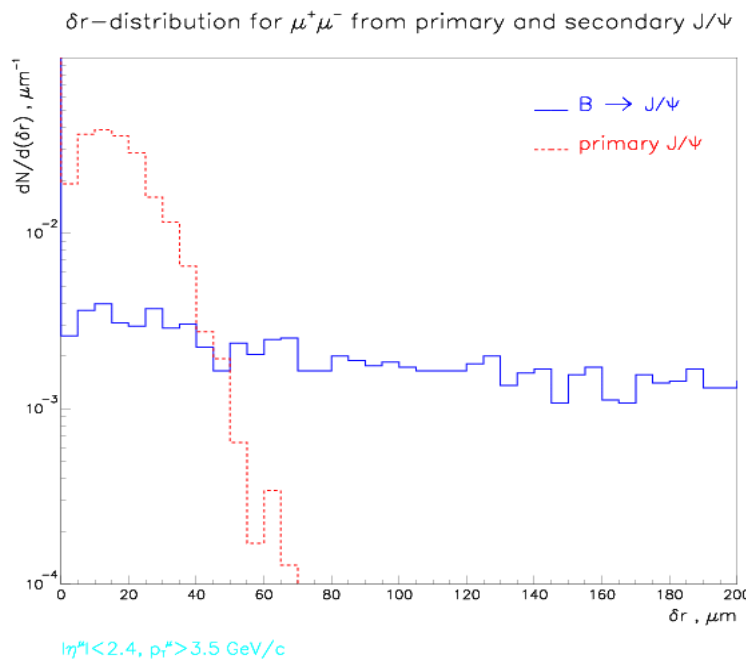
Z^0 can be measured with muon system alone and with muon+tracker systems.

Heavy-quark b,c → μ /J/ψ +X
Secondary vertex finding and correlated background rejection

$B\bar{B} \rightarrow \mu^+\mu^-$



$B\bar{B} \rightarrow J/\psi \rightarrow \mu^+\mu^-$



dr is transverse distance between the intersection points with the beam line (points with minimal distance to the beam axis) belonging two different muon tracks.

I.P.Lokhtin and A.M.Snigirev, J.Phys. C27 (2001) 2365; CMS Note 2001/008

Summary

CMS detector at LHC is well suited for heavy flavour studies.

1) Quarkonia detection.

- **States can be well separated.**
- **The number of events/month will be enough to carry out correlation studies (p_T, event centrality ...).**
- **Significances for Υ are between 70 for Pb+Pb and 1000 for Ar+Ar.**

2) Heavy quarks detection ($b\bar{b}$, $c\bar{c}$).

- **Semi-leptonic $b\bar{b}$-decays will be the main source of dimuons at high-mass domain and can be used to study medium-induced energy loss of b-quarks.**
- **Dimuon spectrum from $B\bar{B}$ decay can be separated from that of Drell-Yan with secondary vertex reconstruction. Also primary and secondary J/ψ can be separated using vertex information.**